11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

THE IMMERSED BOUNDARY METHOD FOR MODELING COMPRESSIBLE FLOWS USING UNSTRUCTURED MESHES

I. Abalakin, A.Gorobets, T. Kozubskaya and N.Zhdanova

Keldysh Institute of Applied Mathematics, 4A, Miusskaya Sq., Moscow, 125047, Russia,
http://caa.imamod.ru/

Key Words: *Immersed Boundary Methods, Compressible Flows, Unstructured Meshes, Computing Methods.*

The interest to immersed boundary (IB) methods increases a lot last decades. The IB method was originally developed in 1972 [1] for simulating inviscid flows with complex embedded solid boundaries on Cartesian grids, but later on a large number of modifications was proposed for a wide class of applications. In the IB approach the presence of complex boundary is replaced by a forcing term which mimics the influence of the obstacle on the flow. The main advantage of all IB methods is associated with the fact that it is not necessary to generate body-conforming grid that is very cumbersome especially in cases with complicated geometry. Moreover in cases with moving obstacles such an approach is relatively simple and it doesn't need a time-consuming deformation or regeneration of the mesh.

Our IB method is based on penalization technique [2] but using unstructured meshes. For compressible flows an external forcing term system which reproduces the presence of the solid body is explicitly added to the momentum and total energy equations of the Navier-Stokes:

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho u_i u_j\right) = -\frac{\partial p}{\partial x_i} + \frac{\partial \sigma_{ij}}{\partial x_j} - \frac{1}{\eta}\chi(\mathbf{x})\rho u_i,$$

$$\frac{\partial E}{\partial t} + \frac{\partial (E+p)u_i}{\partial x_i} = -\frac{\partial u_i \sigma_{ij}}{\partial x_j} - \frac{1}{\eta}\chi(\mathbf{x})\left(E - E_{obst}\right),$$

where $\chi(\mathbf{x})$ is the mask function equal to zero outside obstacle and to one otherwise, E_{obst} is the energy of the obstacle. Here we obtain Brinkmann equations inside the obstacles, which considered as porous media with a very small intrinsic permeability $1/\eta$.

This method was implemented in the computational fluid dynamic in-house code NOISEtte [3]. For the spatial discretization it uses higher-accuracy EBR (Edge-Based Reconstruction) scheme and 2-nd order implicit Newton-based method for the time integration.

Several benchmark cases are presented including shock-cylinder interaction and supersonic flow around a cylinder. Our numerical results were compared with results obtained from body-conforming method (see Fig.1), with results from [2] and with results of the commercial

Fluent code. Comparison shows a good agreement in local and global behavior of the flows considered.

Figure1: supersonic flow around a cylinder – numerical Shlieren-like images obtained from the density: body-conforming (left) and immersed boundary (right) methods.

To demonstrate the ability of the penalization technique, we will show the flows over 3D obstacles with complicated geometry (see Fig 2).

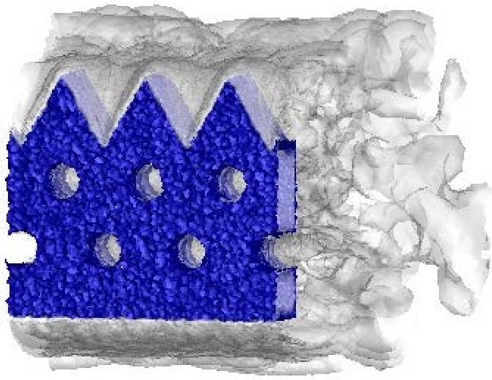

Figure2: flow around a 3D obstacle
(the shape of the obstacle is related with the modeling of deflectors used in aviation).

The results of numerical simulations confirm the potential in using this approach to enforce no-slip boundary condition, near zero velocities and constant temperature inside a solid obstacle. Using unstructured meshes we get a possibility to combine different approaches: body-conforming for obstacles where it is important to provide high accuracy simulation of boundary layers over a surface (e.g. an airframe), and IB method for modeling some moving obstacles (e.g. payload dropped from an aircraft). Other numerical simulations results will be presented.

REFERENCES

[1] CS. Peskin, Flow patterns around heart valves: a digital computer method for solving the equation of motions. PhD thesis. Physiol., Albert Einstein Coll. Med.,Univ. Microfilms. 378, 72-30.

[2] O. Boiron, G. Chiavassa, R. Donat A high-resolution penalization method for large Mach number flows in the presence of obstacles, J. Comp. Fluids, 38, pp. 703-714, 2009.

[3] Abalakin I.V., P.A. Bakhvalov, A.V. Gorobets, A.P. Duben, T.K. Kozubskaya, Parallel research code NOISEtte for large-scale CFD and CAA simulations. Vychislitelnye Metody i Programmirovanie 13: 110-125, 2012 (in Russian).